Parametric Mission Cost Model - Overview
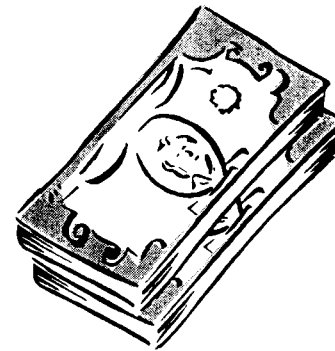
Jet Propulsion Laboratory

Pasadena, CA

Leigh Rosenberg

Kevin Roust

March 3, 2000

- L. Rosenberg
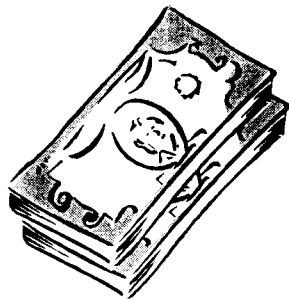- J. Hihn
- K. Roust
- T. Roust
- K. Warfield
- H. Habib-Agahi
- Team X Subsystem Engineers

1 - Why build yet another model?
2 - Model objectives
2 - Current model status (including history)
3 - Modeling approach
4 - Database
5 - Statistical basis
6 - Model summary - WBS, CERs
7 - Validation procedure
8 - Current & future activities

The Old Days -- ≤1990

• Non-competitive proposals
(average cost per project ≈ $1B
without L/V)

• 3-5 proposals (design/cost) per year

• No faster, better, cheaper

• No real cost caps

• Old cost models built to old mission
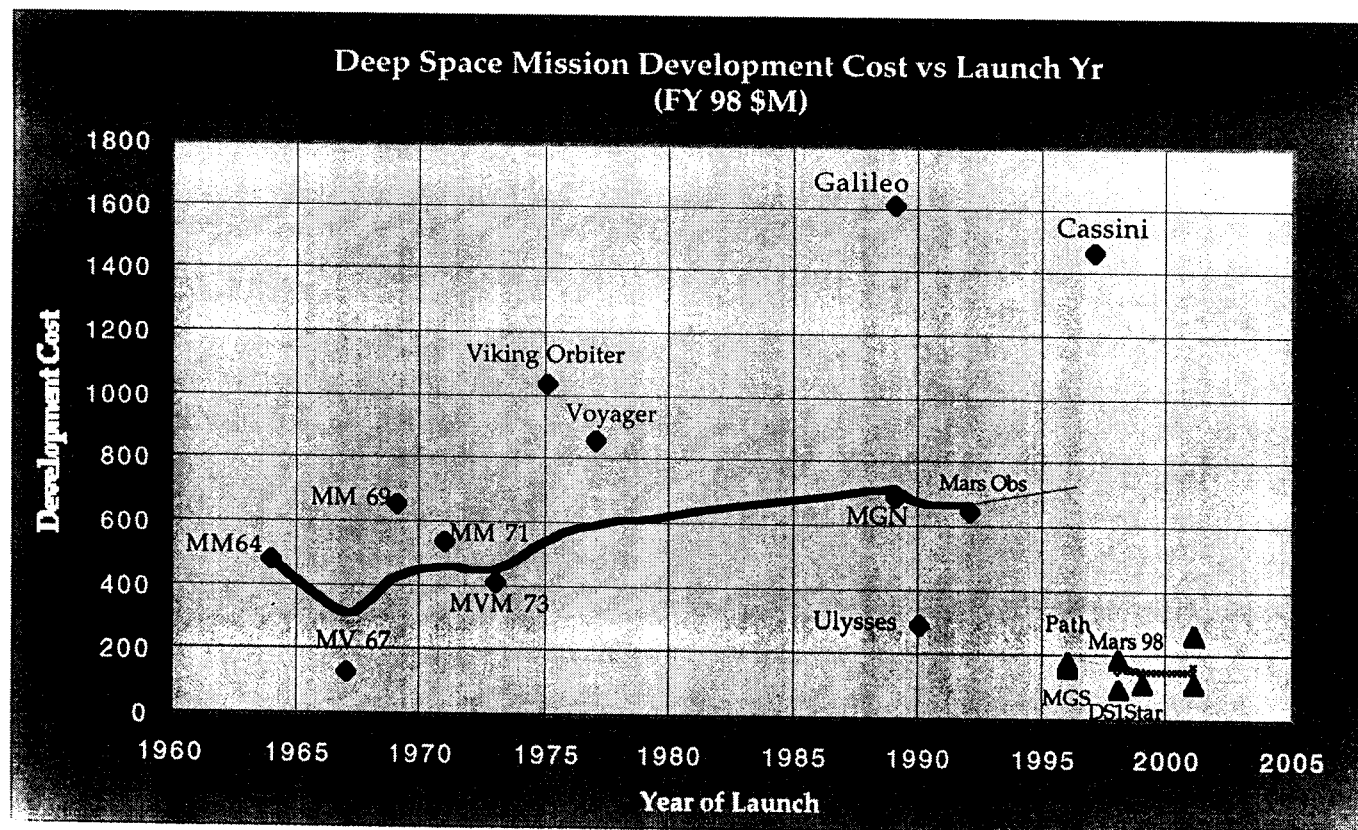style

• Questionable statistical validation
of old models.

Today -- ≥2000

• Competitive proposals - i.e., Discovery, SMEX,
ESSP, etc (average cost ≈ $75 - 300M with L/V)

• 60-100 proposals (design/cost) per year

• Faster, better, cheaper

• Real cost caps

• Defendable, accurate early cost estimates are very
important -

  -Modeling used as grass roots check & when
  detailed design data is not available

  -Validation necessary

• Old cost models no longer applicable

• Outside cost models do not fit many JPL missions
very well:

  – No real deep space cost data beyond Mars

  – JPL has missions to Mercury, Jupiter comets,
  Pluto, rovers, landers, sample return.

March 3, 2000

4

Deep Space Mission Development Cost vs Launch Yr
(FY 98 $M)

- The cost estimation community needs a model that:
  - Is fast, accurate, & consistent
  - Has a minimum of subjective inputs
  - Can be used for cost/performance trade analysis
  - Is defendable (approved by peers, good statistical basis, based on actual mission costs)
  - Can be used to identify proposal/design tall pole issues,
  - Can be used early in proposal cycle to identify proposal areas of strength & weakness, and as a sanity check on proposal cost estimates
  - Can be successfully integrated with other automated design tools
  - Can be used as a surrogate when proposal teams are over committed

- PMCM (version 1) developed in 1997,8
  - Includes instrument model, S/C bus model, secondary CER models, future automated development process assumptions
  - In use for nearly 2 years including Team X, Discovery 98 - Step 1 proposals
- Instrument model developed in 1996 (updated 98)
  - Based on 95 actual flown instruments
  - In use on JPL design teams (including Team X)
- Secondary CER models (project office, ATLO, MA&E) - originally developed in 1996 to provide total project life cycle cost

- PMCM (version 2) completed in 1999. Includes major updates to S/C bus & mission operations models.
- Model reflects JPL's new automated design process.
- Successfully implemented with other JPL automated design tools.
- The model is <u>close</u> to obtaining its objectives.
- The model is used by JPL's proposal design team.
- Year 2000 update is in progress. This includes a formal validation
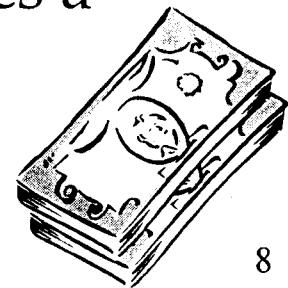
March 3, 2000

- PMCM (version 2) CER update process
  - Collected, reviewed, & verified data
  - Identified key cost drivers (design parameters)
  - Developed CERs for each subsystem based on all available parameters (cost drivers)
  - Reviewed results with Team X subsystem engineers
  - Revised & developed system & mission cost models
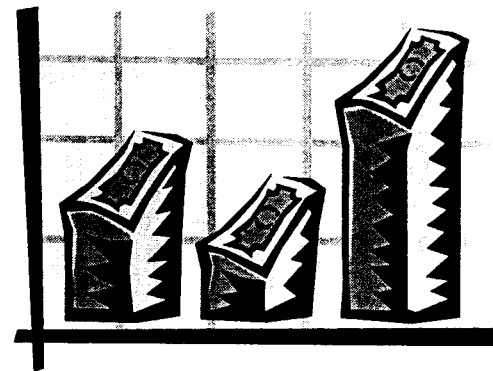 - Encoded model in Excel worksheet (visual basic language)
  - Model validation currently on-going

- Philosophy
  - Avoid mass as a dependent variable
  - Include key design parameters that are likely to be known in early stages of design (high level requirements)
  - Keep model as linear as possible to make parameter interpretation intuitive
  - Use of objective cost drivers, while minimizing use of subjective variables

- Identified 55 potential data records & collected > 200 design parameters (e.g., high level parts lists, tech type, pointing knowledge, BOL power, etc.).

- Deleted incomplete and duplicate records.

- This yielded 43 complete data records based on Team X studies completed from March 97-October 98 that assumed JPL's new FBC development process.

- While significant outliers were identified & removed, the objective was to keep data records as consistent as possible across subsystems
- Used multivariate linear regression & selected cost variables based on causal engineering relationships &:
  - F-ratio > 10 (1% for 10 degrees of freedom), adj R^2 > 75%, student t-ratio > 1.95 (5%)
  - Dropped variables whose direction was inconsistent with engineering principles
  - Kept some variables with low t-ratios if :
    - Variable was a major design parameter
    - Coefficient was consistent with expert engineering judgement

March 3, 2000

Total Project Costs ($M)	
1.0 Project Management	
1.1 Project Manager & Staff	%
1.2 Launch Approval	List
1.3 Planetary Protection Approval	List
1.4 Education & Public Outreach	%
2.0 Science Team	WF
3.0 Mission Design & Project Engineering	%
4.0 Instruments	
4.1 Payload Management	%
4.2 Payload Engineering	%
4.3 Instrument Burdens & Fees	%
4.4 Instrument I	CER
5.0 Spacecraft	
6.0 ATLO	CER
8.0 Reserves	%
9.0 Launch Vehicle	List
10.0 Upper Stage / SRM	List

5.0 Spacecraft	
5.1 Primary Spacecraft	
5.1.1 S/C Bus Management	%
5.1.2 S/C Bus System Engineering	%
5.1.3 S/C Bus Burden & Fee	%

5.1.4 Attitude Control Subsystem

5.1.5 Command and Data Handling Subsystem

5.1.6 Power Subsystem

5.1.7 Propulsion Subsystem

5.1.8 Structures & Mechanisms Subsystem

5.1.9 Telecom Subsystem

5.1.10 Thermal Subsystem

5.1.11 Mechanical Build-Up

5.2 Stage 2

7.0 Mission Operations & Development

7.1 Command, Telemetry, & Mission Data Mgmt

7.2 Navigation

7.3 Experimental Flight Data Products

7.4 Sequence Engineering, Science Observation Planning, Ground Communications & Information

7.5 Project Provided Tasks

7.6 Antenna Charges

Cost Element	Statistically Significant Cost Model Inputs
ACS (R^2 = 88.1, F-ratio = 45.3)	Pointing Knowledge New Design Design Copy # of ACS HW Types # of Actuators
CDH (R^2 = 62.3, F-ratio = 15.9)	No Autonomy Number of Cards Processor < 50mips
Power (R^2 = 95.7, F-ratio = 129)	Array Area Cell Type Number of GPHS Battery Only
Propulsion (CER #1) (R^2 = 72.7, F-ratio = 27.7)	Cold Gas Hydrazine HAN/TEAN Bi-Prop/Dual Mode SEP
Propulsion (CER #2) (R^2 = 81.6, F-ratio = 218)	Ln (Total Impulse)
Structures & Mechanisms (R^2 = 84.4, F-ratio = 109)	# of Mechanism Types # of Mechanisms
Thermal Control (R^2 = 83.0, F-ratio = 47.3)	Destination - Sun/Merc. Launch Mass # of Instruments Destination Pressure

| Cost Element	Statistically Significant Cost Model Inputs
Telecommunications (R^2 = 89.0, F-ratio = 32.3)	Ln (Downlink Datarate) Antenna Diameter Range (SC-Earth) Optical Secondary – UHF Secondary – X-band Mission Class Subsystem Redundancy
Mechanical Build-Up (R^2 = 82.2, F-ratio = 158)	Spacecraft Dry Mass
ATLO (Engineering Algorithm)	Total of Subsystem Costs # of Instruments # of Spacecraft Elements
GDS/MOS (Engineering Algorithm - TMOD Pricing Algorithms)	# of Instruments Satellite Tour Length Aerobraking Length Target Body Orbit Length Cruise Length Phase A/B Length Phase C/D Length DSN Schedule (# Weeks, Passes/Week, Hours/Pass, Antenna)

- For each element of the power subsystem (power generation, energy storage, electronics), collected data on technology used and size of the element.
- Data was also collected on key system parameters (thermal environment, radiation total dose), mass by element, & cost by element - total of 30 exogenous variables.
- Analyzed linear & log-linear forms as well as interactions between size and tech type
- Developed two models based on (1) array area and (2) beginning of life power
- Reviewed by Team X power subsystem engineers
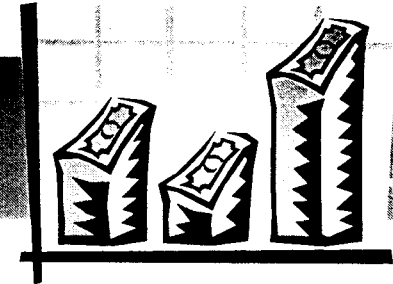- 2 outliers excluded -- unusual technologies (CIS array, thermal-mech-elec conversion)

Power Subsystem CER (R^2 = 95.7%, F-ratio = 129)

Variable	Coefficient	t-ratio	Significance
Constant	$5,477 K	6.25	< 0.0001
Battery Only	- $4,149 K	-1.77	0.0887
Array Area (m^2) – Si	$ 253 K	4.14	0.0004
Array Area (m^2) – GaAs	$ 440 K	4.9	< 0.0001
Array Area (m^2) – Adv. Cells	$ 445 K	22.8	< 0.0001
Number of GPHS	$4,854 K	13.7	< 0.0001
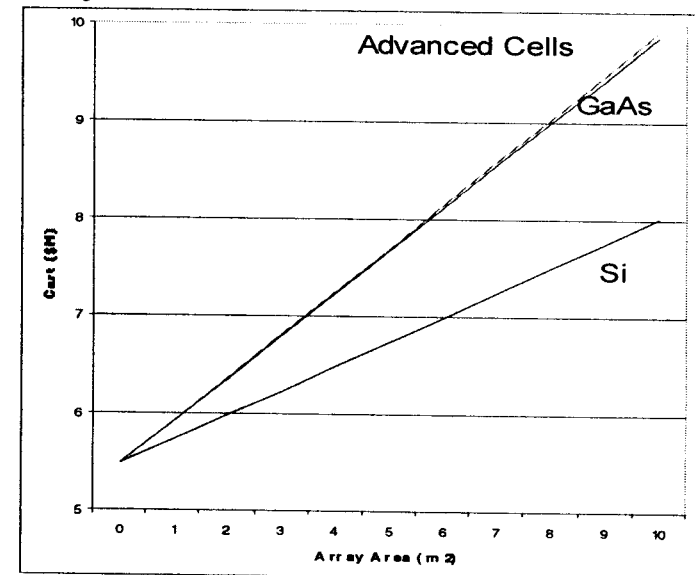
March 3, 2000

- PMCM (version 2) has complete high level WBS containing ≈50 CERs. There were 15 new CERs in 1999.

- It produces a breakdown of life cycle cost results by phase including:
    - Formulation
    - Implementation
    - Operations

- Out of 200 design parameters identified & tested, 47 were found significant

- Review model structure (replicates project WBS)
- Review subsystem CER's with pertinent JPL engineers
- Tested version 1 vs. Discovery 98 proposals
- Currently testing version 2 & version 1 vs. actual missions/winning step 2 proposals (Genesis, Stardust, DS-1, MGS, Inside Jupiter, Deep Impact, Mars Pathfinder, Cloudsat, Cassini, Mars 98 (Orbiter & Lander))
- Peer review board evaluation

March 3, 2000

17

- Model structure replicates Team X design process and uses Team X WBS to determine total project cost.

- Project structure/flow that is modeled has been reviewed by Team X engineers and Team X customers over the last 5 years.

- Individual CER's have been reviewed & verified with pertinent JPL subsystem engineers.

Disc 98-Step 1 JPL Proposals (FY 98 $M)

	Proposal Grass Roots Costs	PMCM (ver 1) Total Project Cost	± %
Deep Impact	204	254	25%
Gulliver	264	221	-16%
Hermes	267	301	13%
Hummingbird	260	249	-4%
Immpact	151	234	55%
Inside Jupiter	227	200	-12%
Janus	239	252	5%
Kitty Hawk	134	150	12%
Lunar Star	111	111	0%
MBAR	240	271	13%
MUADE	125	138	11%
New World Exp	267	269	1%
Quicksilver	276	287	4%
Vesat	191	212	11%
VEVA	269	242	-10%

- Version 1 did quite well (13 of 15 within ±20%).

March 3, 2000

Validation of Version 2 - Test Cases vs Actuals & Step 2 Proposal Costs (FY 99 $M)

Mission	Actual Cost	Ver. 1	± %	Ver. 2	± %
DS-1	195.4	207.0	5.9%	203.8	4.3%
Genesis	210.2	218.4	3.9%	221.7	5.5%
Stardust	201.6	178.5	-11.5%	187.9	-6.8%
MGS	229.3	260.6	13.7%	249.7	8.9%
Inside Jupiter	269.0	255.6	-5.0%	227.5	-15.4%
Deep Impact	243.0	324.1	33.4%	286.8	18.0%

- Test case results look good
  - Version 1 <±20% on 5 of 6 cases (a little better than Disc 98 - Step 1)
  - Version 2 <±20% on all 6 cases
  - "Actuals" range is -7% to +9% -- closer fit than Version 1.
  - 5 missions are being added

March 3, 2000
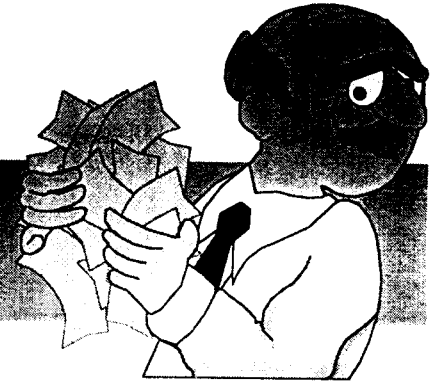
- **Areas we are addressing in FY 2000 and in the near future**
  - Data set is being updated (current data is ≥ 1 year old)
  - Detailed SW cost algorithm being developed
  - Secondary CER's need review (i.e., project office, MA&E, sys eng)
  - Participating within advanced PDC design team
  - Instrument model to be updated (current model is 2 yrs old)
  - Documentation started
  - Risk, uncertainty, factors for new technologies
  - Schedule vs. cost algorithm
  - Probabilistic cost estimating tool
  - To better meet customer requirements, other versions of model are needed (simplified version for earlier use, element level, etc.)